LSHSS

Article

Assessment and Treatment of Working Memory Deficits in School-Age Children: The Role of the Speech-Language Pathologist

Donna Boudreau[a] and Amy Costanza-Smith[b]

Purpose: To review research addressing the relationship of working memory (WM) to language development and academic functioning and to consider the role of the speech-language pathologist (SLP) in assessment and intervention of WM difficulties in school-age children.
Method: Aspects of WM critical to language acquisition and academic success are defined, and the importance of WM to language development and learning is discussed. Subsequently, strategies for assessing WM skills in children are presented. Following a discussion regarding the assessment of WM demands in the classroom, intervention strategies are provided.
Results: Children with poor WM skills are likely to experience significant difficulty in academic settings. Evidence-based strategies for both reducing WM demands and improving functional WM skills are reviewed.
Conclusion: Research to date has documented that children with language impairments frequently have poor WM skills. SLPs can support poor WM skills by considering both modifications to the environment and child-enacted knowledge and skills, which may serve to reduce the impact of poor WM skills on learning and academic success.

Key Words: working memory, language impairment, language assessment, language intervention, phonological memory

Substantial growth in research investigating the relationship of working memory (WM) to language development and learning has occurred during the past 20 years. WM has been implicated in the rate at which children learn new vocabulary; comprehend language (oral and written); acquire literacy skills; and gain efficiency in math, reasoning, and problem-solving tasks (Adams, Bourke, & Willis, 1999; Alloway & Alloway, 2010; Cain, Oakhill, & Bryant, 2004; De Jong, 1998; Passolunghi & Siegel, 2004; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Swanson, Cochran, & Ewers, 1989; Swanson & Sachse-Lee, 2001; Vanderberg & Swanson, 2007; Vukovic & Siegel, 2010). Children's WM abilities at school entry have been shown to predict their overall academic attainment through adolescence (Alloway, 2009; Alloway et al., 2005; Gathercole, Brown, & Pickering, 2003; Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegmann, 2004), serving as a better predictor of school success than IQ (Alloway, 2009). The purpose of this article is to consider the implications of WM deficits to school-age children's academic success and to provide suggestions for ways that speech-language pathologists (SLPs) can assist children with such deficits. Following a theoretical discussion of the concept of WM, studies addressing the contribution of WM to language acquisition and literacy development, as well as the development of WM abilities in children with language impairments (LI), are reviewed. Subsequently, tools for assessing WM abilities, as well as implications of poor WM abilities to the assessment of language and literacy, are considered. We conclude with suggestions for practioners of ways to support children with WM difficulties in educational and clinical settings.

[a]University of Northern Colorado, Greeley
[b]Oregon Health Sciences University, Portland
Correspondence to Donna M. Boudreau: donna.boudreau@unco.edu

Editor: Marilyn Nippold
Associate Editor: Shari Robertson
Received December 16, 2009
Revision received May 15, 2010
Accepted October 15, 2010
DOI: 10.1044/0161-1461(2010/09-0088)

WM DEFINED

There are several aspects of memory that are important for language learning and use. These include short-term memory (STM), long-term memory (LTM; including semantic and episodic memory), and WM (Hood & Rankin, 2005). STM involves the temporary storage of information (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Minear & Shah, 2006). An example of STM would be immediately recalling a list of items on a shopping list or a recently heard telephone number, or obtaining items identified by a teacher to complete a given task (e.g., "Take out your pencil, markers, and writing journal."). Comparatively, LTM serves as long-term storage for information within an individual (Cowan, 1998). LTM has a potentially infinite capacity (that is difficult to measure), and information from LTM must be brought to a conscious level in order to complete a given task. LTM is critical for accessing previously learned information and for learning and retaining new information (Hutchinson & Marquardt, 1997; Jones, Gobet, & Pine, 2007).

Of particular importance to higher level language and cognitive tasks, and the focus of the current article, is WM. WM is considered a domain-general system that controls attention and processing of information (Baddeley, 1996). It has been described as the temporary memory used in information processing (Baddeley & Hitch, 1974) or "STM when it is used to solve a problem or perform a task" (Cowan, 1998, p. 4). Thus, WM is information that is in an active and/or accessible state and is used to complete some form of mental activity (Cowan, 1998). Examples of real-life activities that draw on WM include following multiple-step directions that build on each other, counting forward or backward by a set incremental amount (e.g., ± 3), mentally completing a math equation with two-digit or larger numbers, attempting to write down verbatim a series of recently heard sentences, and following the actions of multiple characters over the course of a story. In each of these tasks, information must be temporarily maintained while a mental operation is completed. Stated differently, each of these activities draws on WM.

In the WM model proposed by Baddeley (1990; which provides the theoretical framework for a broad base of research to date), WM consists of a central executive system with two slave systems—a phonological buffer and a visuospatial sketch pad (responsible for storage and processing of visual and spatial information). The phonological buffer contains two subcomponents: an articulatory rehearsal process in which phonological information is maintained in memory through a process of subvocal rehearsal (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1993a), as well as a short-term phonological store (also called phonological STM [PSTM] or phonological WM) that is responsible for the temporary storage and processing of phonological representations. Within PSTM, phonological information is encoded but quickly decays without covert efforts to maintain the information (Baddeley, 1990; Baddeley & Hitch, 1974). In this article, we focus on two mechanisms of WM that play critical roles in language and learning in children: PSTM and the central executive/limited capacity system, which we refer to as functional working memory (FWM).

Baddeley (1996) originally suggested that the central executive serves as a supervisor to other systems, controlling attention and allocation of resources (Parente, Kolakowsky-Hayner, Krug, & Wilk, 1999). The central executive is also thought to control metacognitive processes such as task analysis, strategy selection, and strategy revision (Wynn Dancy & Gillam, 1997). The limited capacity theory of WM (i.e., FWM) was developed by Daneman and Carpenter (1980) from Baddeley's model of the central executive to more fully explain the role of WM in language development. This attentional resource capacity/allocation mechanism (Montgomery, Polunenko, & Marinellie, 2009) encompasses both the amount of resources available to complete a task requiring mental energy (capacity) as well as the flexibility in which an individual allocates available resources between simultaneous demands of storage and processing (Baddeley, 1996; Montgomery et al., 2009). In this model, WM is viewed as the dynamic allocation of a limited capacity of resources that perform the language processes and store the transitional and final products (Just & Carpenter, 1992). Individuals are thought to vary in their level of resource capacity, with limitations in resources attributed to the amount of processing capacity (effort and cognitive ability) available at any time (Snyder, Dabasinskas, & O'Connor, 2002; Tompkins, 1995). Thus, tasks that place a demand on the system that is greater than the resources available will result in performance difficulties (Just & Carpenter, 1992).

THE RELATIONSHIP OF WM AND LANGUAGE DEVELOPMENT

Vocabulary

WM, and more specifically, PSTM, plays an important role in the early stages of language acquisition, particularly in relation to vocabulary development. Children's abilities to encode acoustic information into phonological codes and temporarily maintain phonological information (typically measured using a nonword repetition [NWR] task) are related to their ability to construct a long-term phonological representation of a new word (Baddeley, 1996). This skill is critical for the development of early vocabulary for both typically developing children and children with LI (Avons, Wragg, Cupples, & Lovegrove, 1998; Edwards, Beckman, & Munson, 2004; Ellis Weismer & Edwards, 2006; Gathercole & Baddeley, 1990b; Gathercole & Baddeley, 1993b). Difficulty with processing resources is thought to be the root problem of poor vocabulary skills in at-risk children (Gilliver & Byrne, 2009).

Studies that examined phonological memory skills and vocabulary acquisition in varied age groups found that differences in NWR tasks on low as compared to large phoneme sequences varied for children with smaller versus larger vocabularies (Edwards et al., 2004; see also Gupta & Tisdale, 2009), suggesting that PSTM is an important contributor to the early development of vocabulary but that other cognitive processes and language skills become more critical as a child's linguistic skills develop. PSTM also has been shown to contribute to grammatical accuracy and morphology in at least some languages (Gathercole, 1995; Thordardottir, 2008). Work with young preschool children has also demonstrated a relationship between PSTM and mean length of utterance (MLU; Adams & Gathercole, 1995).

Language Comprehension

Language comprehension requires children to store information received verbally for the extent of time needed to process and construct an appropriate interpretation of the sentence (Montgomery, 1995; Montgomery, Magimairaj, & Finney, 2010). In complex sentences that include clauses/phrases in the medial or final position of the sentence (e.g., relative clauses), information from earlier parts of sentences may be forgotten, or storage and processing trade-offs may occur when a large amount of resources is dedicated to processing some aspects of syntax–semantic relationships, leaving fewer resources available to maintain earlier information processed or later information received (Montgomery, 2000a). In a series of studies designed to investigate the relationship between PSTM, WM, and sentence comprehension in school-age children with LI and peers matched for age and/or language skills, experimental sentences consisted of redundant (but not linguistically more complex) information, effectively increasing their length without increasing the processing demand (Montgomery, 1995, 2000a, 2000b; Montgomery & Evans, 2009; Montgomery, Magimairaj, & O'Malley, 2008). Both PSTM and FWM were found to be significant predictors of comprehension of complex sentences (see also Botting & Conti-Ramsden, 2001; Thordardottir, 2008). For participants with specific language impairment (SLI), even simple sentences required significant PSTM resources (Montgomery & Evans, 2009).

More recent work examined the role of WM in comprehension of oral narratives, which requires a child to create a mental model of a text (storage demand), maintain/modify this model in WM, and integrate large chunks of new information received into the stored mental representation to allow for changes/updating of the mental model (processing demand; Montgomery et al., 2009). From a theoretical framework, a child's ability to complete a WM task that requires storage and processing of information while simultaneously inhibiting information that is not related to the task at hand is closely aligned with the process of reading comprehension. In a recent study examining the relationship between WM and narrative comprehension in 6- to 11-year-olds ($N = 67$), measures included a digit span task (PSTM), a measure of capacity/storage (FWM), and the comprehension section of the Test of Narrative Language (Montgomery et al., 2009). Results revealed that FWM (but not PSTM) made a significant contribution to children's ability to answer factual and inferential questions on the narrative measure. The authors attributed these findings to the fact that whereas PSTM is required to maintain sequences of verbal information in memory until they can be processed, it is FWM that is required to establish a coherent mental model of events (Montgomery et al., 2009).

Academic Achievement

WM abilities have been implicated in broad studies of academic achievement as well as more narrow investigations of literacy acquisition and mathematical skills (Berninger et al., 2008; Cain et al., 2004; Gathercole, Alloway, Willis, & Adams, 2006; Gathercole, Willis, Emslie, & Baddeley, 1992; Georgiou, Parilla, & Papadopoulos, 2008; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Swanson & Berninger, 1995; Swanson & Jerman, 2007; Torppa, Poikkeus, Laakso, Eklund, & Lyytinen, 2006; Yuill, Oakhill, & Parkin, 1989). Decoding a novel word requires a child to break a word into its individual sounds and hold the accompanying phonological representations in memory until each letter/letter sequence is encoded and can be blended together to form a word—a process similar to writing and spelling as a child breaks each word into its individual parts, accesses the accompanying phonological representation in memory (or letter–sound), and represents each sound with a graphic symbol. Studies have shown that PSTM at age 4 is a significant predictor of reading abilities at age 8, even when controlling for age and nonverbal intelligence (Gathercole et al., 1992). In a longitudinal examination of the relationship of PSTM and literacy (i.e., decoding, reading comprehension, and spelling) in adolescents with SLI, participants with good NWR skills (e.g., good PSTM) performed better on literacy measures than did children with poor NWR skills, most notably on decoding and spelling tasks. This relationship was not unidirectional, as language and literacy skills at age 11 predicted NWR skills at age 14 (Conti-Ramsden & Durkin, 2007).

Cain et al. (2004) investigated the relationship between WM capacity and reading comprehension in a group of school-age children ($N = 102$) 7 to10 years of age over a 2-year period. Findings revealed that verbal FWM was a significant predictor of reading comprehension, beyond the contributions made by other variables at each point in time. FWM is most likely to contribute to reading comprehension when the amount of text a child is able to read places demands on his or her WM. For example, Seigneuric and Ehrlich (2005) conducted a longitudinal investigation of the contribution of WM capacity to reading comprehension in French-speaking children who were evaluated in Grades 1, 2, and 3 ($N = 74$).

Although FWM failed to account for a significant proportion of variance in measures of reading comprehension at 1st and 2nd grade (when the amount of text a child is able to read is more limited), FWM at Grade 2 was correlated with 3rd-grade reading comprehension. Importantly, the predictive value of FWM increased over time, and WM was a significant predictor of reading comprehension (along with decoding skills and vocabulary) in 3rd grade (see also Seigneuric, Ehrlich, Oakhill, & Yuill, 2000; Swanson & Jerman, 2007). Findings from a recent meta-analysis examining the contribution of WM to reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009) suggested that WM plays an important role in children who are experiencing comprehension difficulties when the measure of WM requires both storage and processing, rather than storage only, of verbal information.

WM IN CHILDREN WITH LI

Theories addressing particular WM deficits observed in children with LI include difficulty with attention or perception, limited capacity in PSTM, limitations in accessing information from LTM, reduced processing speed, as well as a broader general capacity limitation (Archibald & Gathercole, 2006; Gathercole & Baddeley, 1990b; Gillam, 1997; Leonard et al., 2007; Montgomery & Evans, 2009). What holds constant across these theoretical perspectives is the notion that WM consists of both processing and storage of information, and that tasks that are particularly demanding from either a storage and/or a processing perspective result in fewer resources available for other aspects of a task.

The important roles that PSTM and FWM play in language acquisition and academic success has prompted researchers to look more closely at these components of WM in children with LI. Studies have found that children with LI perform more poorly than typically developing peers on PSTM tasks (Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000; Leonard et al., 2007), with scores on NWR tasks serving to successfully discriminate between children with LI and controls (Gathercole & Baddeley, 1990a). A study by Bishop, North, and Donlan (1995) of twins suggests that difficulties in PSTM in children with LI are highly heritable, and may in fact constitute a phenotypic marker of children with LI.

Limitations in FWM abilities in children with LI and language-learning disabilities have also been well documented. School-age children with language-learning difficulties consistently perform more poorly on tasks that tap into storage and processing components of WM when compared to typically developing peers (Archibald & Gathercole, 2006; Ellis Weismer, Evans, & Hesketh, 1999; Riccio, Cash, & Cohen, 2007). These difficulties are often attributed to processing capacity limitations as well as difficulty in inhibition and executive function (Brocki, Randall, Bohlin, & Kerns, 2008; Isaki, Spaulding, & Plante, 2008; Marton, Kelmenson, & Pinkhasova, 2007). Additional work has attempted to substantiate physiological differences that may underlie behavioral measures of WM difficulties in children with SLI. In a study of adolescents with SLI (Ellis Weismer, Plante, Jones, & Tomblin, 2005), functional magnetic resonance imaging was used in combination with a behavioral task to measure WM and processing capacity limitations in this population. Results revealed hypoactivation in regions associated with attention, memory, and language processing, as well as differences in patterns of coordination activation among brain regions, providing support for physiological differences related to WM in children with SLI.

WM IN ASSESSMENT

In light of the significant role WM plays in language acquisition and learning, SLPs should consider WM when completing a language assessment. SLPs who work on multidisciplinary teams may have access to a wealth of information regarding WM from other team members, as psychologists frequently assess WM as part of a standardized assessment of intelligence and academic achievement. For example, on the Wechsler Intelligence Scale for Children—IV (WISC–IV; Wechsler, Kaplan, Fein, & Kramer, 2004), a child's full-scale IQ is based on four composite scores, of which one is WM. Similarly, the Stanford-Binet Intelligence Scale (Gale, 2003) includes WM measures in the calculation of both nonverbal and verbal IQ scores.

When WM information is not available, SLPs may choose to assess WM directly, using a WM-specific measure as part of a comprehensive language evaluation. This may be warranted if memory is a presenting concern (e.g., traumatic brain injury), if memory difficulties have been implicated by other testing or observation of a child's functioning, or if the clinician wants to consider the underlying factors that may contribute to language or academic difficulties. In light of evidence that WM difficulties often are viewed as attention problems by teachers, concerns about a child experiencing difficulty in completing tasks, keeping pace, or following instructions may also serve as red flags for possible WM deficits (Gathercole, 2008). In children, WM-specific measures include measures of PSTM and FWM.

PSTM

For children who are experiencing vocabulary or literacy difficulties (e.g., decoding or spelling), an assessment of PSTM may be particularly important. PSTM is typically measured using NWR tasks, which are designed to measure phonologic processing efficiency independent of lexical knowledge (Dollaghan, Campbell, Needleman, & Janosky, 1997; Gillam, Hoffman, Marler, & Wynn-Dancy, 2002). NWR requires PSTM because to repeat a nonword, a person has to maintain an accurate phonological representation of

unfamiliar phonologic information in memory (Jarrold, 2001; Montgomery, 2002). Performance on NWR tasks is dependent on the ability to encode and produce the phonological information presented (Jarrold, 2001). Two NWR measures that have been used frequently in research to date with children are the Children's Test of Nonword Repetition (CNrep; Gathercole & Baddeley, 1996) and the Nonword Repetition Task (NRT; Dollaghan & Campbell, 1998). Both tasks require the child to repeat lists of nonwords, which systematically vary in both the number of nonwords included and the number of syllables represented in the nonword. Nonwords are used rather than real lexical items to avoid children drawing on prior learned knowledge or lexical abilities (Bishop et al., 1996). In other research, NRT performance was found to be influenced more strongly by cognitive deficits, and the CNRep was more sensitive in identifying phonologic memory deficits in children with SLI (Archibald & Gathercole, 2006).

In addition to experimental tasks, an increasing number of standardized language measures are including an NWR task. This is due in part to research indicating that performance on PSTM is useful for differentiating typical from disordered populations (Dollaghan et al., 1997; Engel, Santos, & Gathercole, 2008). NWR tasks have also been found to be less culturally biased than many language measures currently available (Ellis Weismer & Evans, 2002; Engel et al., 2008; Rodekohr & Haynes, 2001). Examples of language measures that contain an NWR task include the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999), which is normed on children 5 to 24 years of age, as well as the Working Memory Test Battery for Children (WMTB–C; Pickering & Gathercole, 2001), which includes subtests that measure PSTM as well as FWM and visuospatial WM. It should be noted, however, that NWR in isolation may not be sensitive for all populations/dialects of children (Oetting & Cleveland, 2006).

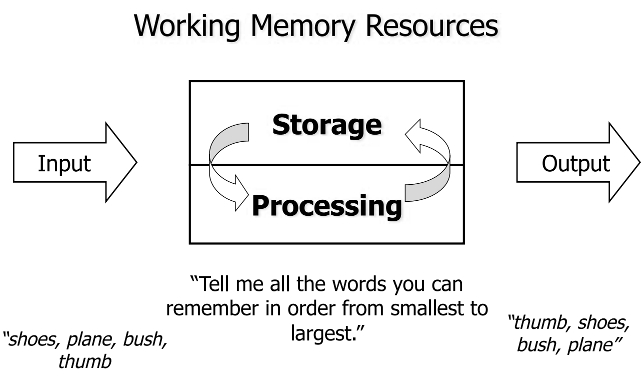
FWM

For children who are experiencing classroom difficulties with following complex directions, oral or reading comprehension, or completing tasks that require completion of mental operations (e.g., word/story problems, math equations performed mentally), an assessment of FWM may provide some insight into these challenges. Measures of FWM are designed to evaluate how much information children can maintain in storage while they simultaneously perform processing operations (Baddeley & Hitch, 2000; Hitch, Towse, & Hutton, 2001). Therefore, WM span is assessed using tasks that draw resources from both storage and processing, or dual tasks (Engle, 2001). In this type of assessment, an extrinsic memory load, such as a series of words to be remembered, is added to a task requiring processing resources (Just & Carpenter, 1992). The processing component is typically a form of symbolic manipulation (Duff & Logie, 2001), such as comprehending an oral or text sentence (reading or listening span), putting words into categories (word memory span), or completing a mathematical operation (operation span). Storage is simultaneously tapped through an extrinsic memory load, such as remembering a list of words or numbers. In this way, storage resources are consumed for retention of the extrinsic memory load in WM. As the extrinsic memory load increases, processing declines because available resources are shared between storage and processing (Duff & Logie, 2001; Just & Carpenter, 1992). Differences in the coordination of the simultaneous functions of storage and processing produce individual differences in performance (Montgomery, 2002).

The competing language processing task (CLPT; Gaulin & Campbell, 1994) is an experimental task that was developed to assess WM span in children. The CLPT is based closely on the reading span task (Daneman & Carpenter, 1980) and is commonly used in research. The CLPT consists of 42 true/false sentences presented in sets of 1–6 sentences. During the task, the child is presented with a sentence and is asked to assess the truth of the sentence by verbally stating whether it is true or false while simultaneously holding the last word of each sentence in WM. At the end of each set of sentences, the child is asked to recall the last word of each sentence in the group in order. Comprehension of the sentences and storage of the final words draw on the available pool of resources (see Figure 1). According to the limited capacity model, performance in comprehension, final word retention, or both will decline when the two tasks conjointly exhaust the available resources (Gaulin & Campbell, 1994). The authors consider word recall to be an estimate of memory capacity for lexical information as well as an indication of the efficiency of the processing resources being allocated (Gaulin & Campbell, 1994). Because the CLPT holds processing constant (single sentence understanding), it is primarily a measure of storage (Montgomery, 2002).

In addition to the experimental task (CLPT), at least one commonly used standardized language test now includes FWM tasks. The Clinical Evaluation of Language Fundamentals—Fourth Edition (CELF–4; Semel, Wiig, & Secord, 2003)

Figure 1. The Competing Language Processing Task (Gaulin & Campbell, 1994) as a measure of limited capacity.



includes a WM index that is based on two subtests: Number Repetition and Familiar Sequences. The Number Repetition subtest includes forward and backward digit span. Whereas forward span is considered a measure of STM, backward span is considered a more difficult task because items must not only be stored but also reversed, thereby taxing both processing and storage resources in WM (see Gathercole & Pickering, 2000). The Familiar Sequences subtest considers a child's functional memory of numbers, days of the week, and months of the year and assesses WM by having the child recall the information backward or by using calculations (e.g., "Count starting with 1 by adding two each time. For example, 1, 3, 5."). Scoring of the Familiar Sequences subtest is also based on how quickly a child responds. These two subtests combine to form the Working Memory Composite. This index is an accessible complement to standardized language assessment. Additionally, the WMTB–C (previously described) includes an assessment of central executive functioning and may be administered by an SLP (Pickering & Gathercole, 2001). Recently, a teacher rating scale based on observations was developed to serve as an initial screening tool when concerns about WM have been identified (Alloway et al., 2009). Named the Working Memory Rating Scale, it consists of 20 descriptions of problem behaviors in which the teacher rates a child on a 4-point scale ranging from *not typical at all* to *very typical*. It has reported good internal reliability and adequate psychometric properties (Alloway et al., 2009).

WM Demands of Assessment

It is also important for SLPs to consider the WM demands inherent in measures of speech, language, and reading. To do so, clinicians can examine storage and processing requirements of language assessment tools and consider how these demands may influence a child's performance. Tasks that require a child to hold onto multiple pieces of information and engage in a mental activity require WM. Examples include judgment tasks where a child must hold on to a verbal target and compare it to information stored in memory, or tasks that require a child to determine which items may be similar or different based on a presented criteria. Analyzing the pattern of breakdowns observed (or task analysis) can make standardized testing more informative (Ellis Weismer & Evans, 2002; Lahey & Bloom, 1994). For example, performance on sentence imitation tasks serves as a marker of both WM and LI (Archibald & Joanisse, 2009). If a child performs better on a sentence imitation task (considered mostly rote memory) compared to a task in which comprehension of the sentence must be demonstrated (such as a following directions task), then SLPs should consider a child's WM abilities as a way of accounting for this discrepancy. In this example, the child has the PSTM skills to repeat a sentence (storage) but may not have the capacity needed to act on the sentence (processing).

INTERVENTION

Gillam (1997) suggested that given the critical role language plays in memory and memory plays in language, it is difficult to separate language intervention from the topic of memory. When working with children known to have WM limitations, clinicians will want to be particularly considerate of the potential impact of these difficulties on a child's response to intervention, as well as his or her academic functioning in the classroom.

There are several theories about the ways WM limitations may contribute to poor performance on academic and language tasks. Whereas some theorists subscribe to the notion of differences in overall capacity as being the primary variable that predicts performance on WM and related measures, others acknowledge the importance of domain-specific knowledge and/or use of strategies to the completion of a given task with significant WM demands (Minear & Shah, 2006). Some support for this latter perspective is observed when considering individuals who may perform particularly well in some real-life contexts (e.g., a waiter who does not need to write down orders) but may not perform particularly well on clinical measures of WM (Minear & Shah, 2006). In actuality, there is the likelihood that how a task with significant WM demands is performed reflects some combination of knowledge representation, limitations in capacity, and strategy use (Minear & Shah, 2006).

The notion that WM and processing capacity may be biologically predisposed begets the question of (a) whether we can modify this cognitive process that is so critical for language acquisition and learning, and (b) whether changes in WM skills will result in improved language abilities or academic performance. Although a number of intervention studies have successfully retrained WM skills in patients with traumatic brain injury (Cicerone, 2002; Parente et al., 1999; Vallat et al., 2005) and schizophrenia (Wexler, Anderson, Fulbright, & Gore, 2000), research with children is only beginning to emerge. Despite the fact that studies to date have been completed with populations of children other than those with LI, results have been promising. For example, Klingberg et al. (2005) investigated the effects of computerized training to improve WM skills in school-age children with attention deficit hyperactivity disorder. Intervention completed over a 5-week period consisted of performing both visuospatial and verbal WM tasks daily for approximately 40 min/90 WM trials presented within a computer program (termed Cogmed for Cognitive Memory Training Program; Klingberg et al., 2001). Tasks were increased in complexity based on children's level of success on a given trial. In both posttreatment assessment as well as follow-up 3 months later, children in the treatment group outperformed the control group on a measure of visuospatial WM skills as well as measures of verbal WM (see also Holmes, Gathercole, & Dunning, 2009; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg, Forssberg,

& Westerberg, 2002; St. Clair-Thompson, Stevens, Hunt, & Bolder, 2010).

Similar results were obtained with preschool children in a 5-week computerized training program designed to improve visuospatial WM or inhibition. Only the training group demonstrated improvements on trained and untrained visuospatial and verbal WM tasks (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). A critical component of successful intervention projects to date has been the inclusion of tasks that place significant storage and processing demands on the system, as well as systematically increasing/decreasing demands based on individual performance. Generalizing research findings to children with LI should be approached cautiously, however, given the fact that studies to date have not targeted this population specifically. Interestingly, research using functional magnetic resonance imaging as a tool to measure changes in brain activity following WM training in young, healthy adults has shown increased activity in areas of the brain associated with WM (e.g., dorsolateral, prefrontal, parietal association contexts, as well as left inferior frontal cortex) (Wexler et al., 2000; see also Olesen, Westerberg, & Klingberg, 2004). These findings are promising in their substantiation of physiological changes following WM intervention.

In addition to considering training WM abilities directly, there are a number of other ways clinicians can support WM difficulties and their impact on learning and academic functioning. The goals of such efforts are to reduce demands in those contexts in which it is believed that WM limitations are impacting performance, while at the same time improve the efficiency in which the child uses available resources/capacity. In the following section, we present our suggestions for evaluating the current WM demands of the classroom. Subsequently, we discuss strategies for modifying the environment as well as ideas for addressing child-specific knowledge, skills, and strategies.

Identify WM Demands of the Classroom

Classroom and discourse practices. Observing and analyzing the WM demands of both classroom discourse and assignments is an appropriate first step for the SLP. Of significance is the identification of learning contexts in which WM limitations are likely to influence performance. There are some types of instructional activities and practices that are inherently likely to place greater WM demands on a child than others, such as learning situations in which a child is asked to store a considerable amount of information while at the same time engage in mental operations related to information stored. Gathercole et al. (2006) studied WM demands within regular education activities of a small group of 5- and 6-year-olds with poor WM abilities in an attempt to identify situations in which WM demands contributed to the children's ability to complete target activities. Results revealed particular difficulties in the following contexts: classroom instruction (particularly if instructions were lengthy and did not reflect a routine activity of the classroom), completing demanding processing activities that included storage and processing of information (such as counting activities that increased or decreased by a set amount), and writing (including generating sentences or writing to dictation) (see also Alloway et al., 2005). Thus, SLPs should work with teachers to identify those learning contexts that contain significant processing and storage demands—a task likely best completed through observations across the curriculum. SLPs will want to pay particular attention to the language of instruction within the classroom, noting the way in which information is delivered, assignments are communicated, and participation is facilitated. Although significant attention to the WM demands of the language arts curriculum is warranted, it is important to remember that WM demands are not limited to reading and writing activities.

Instructional materials. In addition to considering the WM demands related to oral discourse, SLPs should also consider the WM demands within classroom texts. In early elementary school, the ability to comprehend and construct oral and written stories comprises a substantial component of classroom expectations (McCabe & Bliss, 2003). Research has shown that complex narratives place a greater demand on children than simple narratives do, resulting in poorer performance on measures of narrative production and comprehension (Boudreau, 2007). Observation and analyses of the complexity of stories used in the curriculum, such as the difficulty of language used, the number of episodes included, and the intricacies of interaction of characters, will provide insight into the level of WM demand these texts place on a child. This information can help explain discrepancies in a child's ability to comprehend different texts (oral or written).

WM demands within the context of academic texts should also be considered. Research has demonstrated that processing complex sentences places greater demand on WM than processing simple sentences does (Montgomery & Evans, 2009; Thordardottir, 2008). For example, new concepts and ideas introduced in a 5^{th}-grade science textbook may be within the student's grasp as long as the language used (e.g., vocabulary, syntactic structure) is familiar to the child. In contrast, in scenarios where the child must contribute a great deal of mental resources to the comprehension of word meaning or syntactic frame(s) within a paragraph, it is likely that fewer resources will be available to integrate the content information with previous information to create new knowledge or learning.

Support(s) provided. After evaluating the WM demands of the classroom, SLPs will want to consider the supports/strategies currently in place that may serve to reduce WM demands. For example, the use of visual supports (e.g., writing detailed instructions for a task on the board, using a number line in addition/subtraction equations within the math curriculum) can reduce the amount of information a child must maintain in memory, thereby improving his or her

chance for success on the task or assignment (Gathercole, Lamont, & Alloway, 2004; Minear & Shah, 2006). Evaluating teaching practices currently in place that may reduce WM demands is an important early step in planning appropriate intervention.

Once situations that place particular demands on WM are identified, SLPs can provide support for children by making teachers and other educators aware of the ways in which WM and resource limitations may play out in a child's response to expectations and assignments within the classroom. Additionally, SLPs can provide suggestions for decreasing the overall WM demand(s) of classroom assignments. Finally, SLPs can work directly with children on skills and strategies that will help improve their use of available resources to complete tasks successfully.

Classroom Modifications and Supports

Adult discourse strategies. First and foremost, attention to the task is important, particularly attention to information that is most critical for the task at hand. Repetition is one strategy that assists a child in knowing what is most important from a story, lecture, or discussion; ensuring ample opportunity to store key information in memory. Additionally, the use of "chunking" information, such as summarizing key content or asking students to summarize at varied points along the way, helps to reduce WM demands (Rankin & Hood, 2005).

Children with poor WM often experience task failures after beginning a task, which may be a function of WM overload (Alloway et al., 2009). Thus, it is important that children understand what is expected of them related to a task or assignment, as well as be aware of what they will be asked to do with the information being presented or discussed. This may influence both what is attended to as well as strategies a child may use to remember the information. Rankin and Hood (2005) suggested that children with WM difficulties may also benefit from an example of the targeted end product, providing further support regarding the goal of the task and the expected outcome.

Teachers will also want to ensure that children can remember the requirements of the task they have been assigned by checking in regarding their perceived understanding and/or by requesting students to restate the directions in their own words or demonstrate what they have been told to do (Gathercole et al., 2006). For older children and/or tasks that are completed repeatedly, educators may consider providing a written list of key steps in the process (Rankin & Hood, 2005).

Clinicians and educators should also consider reducing their rate of instruction, as this can assist children with WM difficulties as well. Research has shown that reduced rate results in better word learning in children with LI (Ellis Weismer & Hesketh, 1996; Horohov & Oetting, 2004). Decreasing the rate at which information is delivered may be particularly important when new concepts are introduced or when modifications to the complexity of language used are not possible due to the nature of the assigned task (e.g., reading of Shakespeare in English class).

The WM demands of response environments should be considered as well, as some inherently place a greater demand on WM than others. For example, situations when a student is asked to contribute to a discussion that requires him or her to build on prior contributions to the conversation, or is the third or fourth student called on to answer a question posed, requires a child to hold prior information in memory while at the same time formulate a response. Strategies such as allowing a student to be the first or second contributor to a discussion or recapping key points in a discussion before asking the child to contribute will reduce WM demands, which may allow for greater success in responding to questions presented.

Visual support. The use of visual supports is another way to reduce WM demands in at least some learning contexts. Although research to date is conflicting regarding whether visuospatial WM skills are compromised in children with LI, studies have found that verbal WM skills are more impaired than visuospatial WM skills in this population (Marton, 2008; Riccio et al., 2007). Providing visual support, both when providing information related to assignments and when teaching new information, may be helpful in reducing WM demands and allow children with poor WM skills to be more successful. Examples include providing visual support when providing instructions (e.g., gesturing toward the items needed in a multistep direction, writing a sequence of instructions to be remembered on the board) as well as making information needed to complete a secondary task more accessible (e.g., word wall with high-frequency written words for writing assignments, posting addition and multiplication facts) (Quail, Williams, & Leitao, 2009). Educators should also consider individualizing visual supports and making them personally accessible to a child (e.g., specific to an individual assignment, posted on child's desk or in clear visual sight) as there is some suggestion that supports that are at a distance may make it more difficult for the child to use this information. Educators and clinicians can also consider other contexts where visual demands may reduce the amount of information that needs to be stored in WM. For example, research has found that visual support in the context of providing objects for physical manipulation that correspond with written text can enhance reading comprehension as well as performance on math-based story problems in elementary-age children (Glenberg, Brown, & Levin, 2007; Glenberg, Jaworksi, & Rischal, 2005); this is an outcome likely due in part to the memory support provided by combining verbal information with physical experience.

Preteaching. Educators and clinicians can also reduce demands on WM in the context of academic subjects by preteaching key concepts. Ensuring that background and related knowledge (e.g., relevant vocabulary, literate language features) about a topic has been activated will allow for the

dedication of greater resources to learning a new concept (Klingner, Vaughn, & Boardman, 2007). Although this type of preactivation of information in LTM before completion of a task will be supportive of all children, it may be critical for the child with WM limitations.

Breaking down tasks**.** Finally, children with WM limitations are likely to do better if tasks are broken into smaller parts. By reducing the amount of information a child must process or store for a given task or assignment, we can assist him or her to be more successful. Suggestions include breaking complex directions into a sequence of steps in which each part is a small piece of the larger whole (Gathercole & Alloway, 2008).

Supporting Child-Specific Knowledge and Skills

In addition to modifications to the environment, SLPs will also want to address child-specific variables that would allow the child to manage his or her WM skills and available resources more effectively. Given that any cognitive task requires some level of processing capacity, improved functioning in any aspect of the task that reduces the draw on available resources will allow for a greater amount of resources to be dedicated to other aspects of the task. Key is the notion that WM can be improved when efforts are "highly strategic and specific to the task practiced" (Minear & Shah, 2006, p. 276).

Improve phonological memory. Improving phonological memory may facilitate improved WM abilities, as practice in repeating phonological forms that are unfamiliar may assist children in perceiving "essential combinatorial basis of phonologic structure of language" (Gathercole & Baddeley, 1993a, p. 269; Lindblom, 1989). Enhancing the efficiency of phonological encoding may improve the retention, as well as the quality, of phonological information in WM (Minear & Shah, 2006). In a longitudinal study, a group of Greek-speaking preschool children ($N = 120$) were enrolled in a treatment or control group and were followed through the end of Grade 1 (Maridaki-Kassotaki, 2002). Training was provided for 15 min per day, 4 days per week, over a 7-month period by the experimenter as well as classroom teachers, with the experimental group receiving repeated practice on a target set of nonwords and the control group engaged in art activities. In addition to better performance on NWR tasks at completion of the intervention, the experimental group also demonstrated superior performance on a measure of reading at the end of Grade 1. In light of phonological memory deficits experienced by children with LI, further exploration of phonological memory training in this population of children may be a promising line of research.

Phonological memory may be improved through training of other phonological processes as well (Gillam & van Kleek, 1996; O'Shaughnessy & Swanson, 2000). For example, van Kleek, Gillam, and McFadden (1998) conducted a study addressing phonological awareness in preschool children with identified LI. Intervention focusing on rhyme and phoneme awareness provided over a 9-month period resulted in improved phonological awareness skills as well as significant improvement on NWR tasks. In light of the direct and longstanding impact of phonological awareness training with young children on later reading abilities, it would be of interest to investigate whether training phonological memory through NWR provides any benefit not observed in phonological awareness training (see also O'Shaughnessy & Swanson, 2000).

More recent work has examined the effects of reading and writing interventions on phonological memory skills. In a project designed to improve writing abilities in 4th–6th graders with dyslexia (Berninger et al., 2008), children were randomly assigned to receive either orthographic or morphological spelling treatment in addition to broader strategies related to the writing process (e.g., planning, writing, and revising). Results revealed that the phonological spelling intervention, which included specific training with syllable and phoneme segmentation of unfamiliar words as well as phoneme–grapheme relationships, resulted in children's improved ability to spell, repeat, and read pseudowords. These findings are particularly significant in documenting that the provision of research-based interventions to address literacy difficulties in children with WM difficulties improves both PSTM skills and performance on tasks that require the use of PSTM to be successful.

Increase automaticy of skills. An additional strategy that may serve to decrease WM demands is to make some components of the specific learning situation more automatic. When learning new information, conscious attentional resources are needed. In contrast, tasks that do not require significant resources are considered automatic (Fazio, 1996). It is through repeated practice, as well as overlearning and overrehearsal, that tasks become automatic. With increased automaticity, the amount of resources available to a child is increased, resulting in a "functional" increase in WM (Fazio, 1996; Kail, 1990). Thus, educators and clinicians can consider knowledge and skills important for the completion of an assignment that may become more automatic with repeated practice. This may include mathematical foundations that support higher level math computations (e.g., addition, multiplication facts), knowledge of literate language features to include in story writing or retelling (e.g., knowledge of story grammar), or rhymes that support time concepts (e.g., months of the year, days of the week).

For children with LI, a specific focus on language abilities that are critical for assignments in reading and writing may also help to support WM limitations. Specifically, addressing vocabulary and syntactic structure, particularly those that are tied closely to a given task, is also likely to reduce the demands on available resources. For example, if a child has a stored template of syntactic constructions, this may make constructing utterances less demanding (Adams & Willis,

2001). Intervention targets may include practice in writing routinely used sentence frames for particular classroom activities, such as responding to journal prompts or writing about personal events. Additionally, knowledge of relevant vocabulary ensures that resources are not redistributed in online processing to search for word meaning. For young children, ensuring they can understand and follow temporal directions prominent in the discourse of the classroom may be particularly helpful, as this will reduce the amount of resources needed to process what is being asked of them. This may include using sentence frames with causal or conditional clauses (e.g., if/then), temporal terms (e.g., before, after), or mathematical concepts (e.g., more than, less than).

Another strategy to improve the efficiency with which the FWM system can complete a task is to improve domain-specific knowledge. Studies have found that domain-specific knowledge helps to increase FWM when completing domain-related tasks (Alloway, 2009; Ricks & Wiley, 2009). Learning situations that draw on prior knowledge place greater demand on a child's WM abilities; thus, ensuring background knowledge is readily available will result in greater resources dedicated to the task. Additionally, ensuring children have a schema for repeated classroom experiences/assignments, such as familiarity with the structural organization of textbooks used in history class or the steps required to complete a science lab (e.g., hypothesis, experiments, results, discussion), may help reduce WM demands. This knowledge will reduce the amount of resources that must be dedicated to understanding macro-level knowledge.

Improve metacognition and strategy use. Educators and clinicians can support children with poor WM skills by assisting them to develop metacognition related to their WM limitations. When children are aware of their difficulties, they can better use strategies to support their challenges. Gathercole et al. (2006) found that the children with poor WM abilities who participated in their study had considerable insight into the kinds of difficulties they were experiencing.

In addition to metacognitive awareness, metacognitive skills are also important for compensating or making adjustments for WM limitations. Wynn Dancy and Gillam (1997) described metacognition as "the process through which individuals reflect on the demands inherent in a situation, the skills they bring to a task, and the actions needed to ensure success" (p. 34). Thus, teaching children to analyze a learning situation, particularly as they get older, can enable them to identify appropriate strategies to ensure success in task completion. Research has documented that children with language-learning difficulties are less likely than their typically developing peers to use memory strategies even when specific strategy suggestions are provided (O'Shaughnessy & Swanson, 1998). The teaching of metacognitive strategies may allow children with language-learning difficulties to manage limited resources more efficiently—an act that is likely to improve performance (Minear & Shah, 2006; Swanson, Kehler, & Jerman, 2010). In an investigation of the development of strategy use in 4th, 5th, and 6th graders in the completion of simple addition problems, children were asked to indicate the strategy they used from a choice of four: retrieval (knew or remembered the information in memory), counting (count certain number of times to get the answer), transform (referring to related operations or deriving answers from known facts), or "other." Results revealed that although all children used all strategies, performance was poorer when children's executive WM resources were experimentally manipulated to be taxed (Imbo & Vandierendonck, 2007). As children grew older, however, the negative effects of increased WM load decreased, which suggests that greater WM resources are needed as a skill is first acquired. These findings were interpreted to be the result of age-related changes in strategy efficiency and selections rather than changes in processing demands or encoding abilities. Additional metacognitive strategies that may help children with poor WM perform successfully on academic tasks include the following:

- ***Use of rehearsal strategies.*** Rehearsal usually does not take place before age 7 (Minear & Shah, 2006); however, studies with young adults have shown that training on simple rote strategies improved WM (Turley-Ames & Whitfield, 2003). In a study of undergraduate college students, participants were trained on a variety of WM strategies (e.g., rehearsal, visual imagery, and semantic strategy). Rehearsal was the only strategy that was consistently helpful across participants, with students with low WM abilities at the onset of the project benefitting most from its use (see also Parente et al., 1999). Thus, older children and adolescents can be taught to rehearse information that is critical to a task being completed, which would reduce WM demands. Children may also be taught to chunk words together in systematic ways, making them easier to remember (Minear & Shah, 2006). Research has shown that repeating a limited amount of verbal information helps the information to be maintained in STM (Gathercole & Alloway, 2008).
- ***Task analysis.*** Sohlberg, Mateer, and Struss (1993) taught children to identify the current goal of a task as a way of being more strategic. By analyzing the goal of a task and the steps needed to reach that goal, children may be better able to identify appropriate strategies.
- ***Visualization strategies.*** Gill, Klecan-Aker, Roberts, and Fredenburg (2003) found that children who were taught a rehearsal strategy focusing on visualization improved in their ability to follow instructions. Hood and Rankin (2005) suggested a strategy of "mind mapping" as a way of making verbal information more organized; this includes using key words to help construct a visual representation of a topic area and using symbols to represent how concepts are related (similar to semantic mapping). For children with WM difficulties, there is some suggestion that more complex strategies such as visual representations may prove difficult (Alloway et al., 2009); thus, the amount of cognitive

resources required to implement such a strategy should be weighed against the potential benefit on an individual basis.

- ***Study and organizational skills.*** Children with WM difficulties often struggle with organizing information (Rankin & Hood, 2005). Thus, helping children implement organization and study skills is also important. For older children, this may include strategies for self-generating visual cues (pictures or written words) to represent steps in a process or instructions to follow.

Conclusion

WM abilities are critical for language learning and academic success. A key finding in numerous studies to date is the knowledge that WM difficulties may underlie learning challenges experienced by some children, independent of related cognitive skills (Gathercole et al., 2004). Thus, a first step for SLPs working with children with WM difficulties is to help make others aware of the ways that WM problems can impact language and learning. Considering that WM difficulties in children often are misdiagnosed as attention or behavioral issues, helping teachers and other educators be aware of characteristics of children with WM problems is also important (Gathercole, 2008).

SLPs can also play a valuable role in the assessment of WM when concerns are identified. Evidence that children with LI often experience difficulties in both PSTM and FWM skills when compared to typical peers makes WM an important consideration when completing a language assessment. Understanding a child's underlying WM skills can provide some insight into his or her performance on other assessments, such as language and literacy measures, thereby providing a better picture of a child's language and academic difficulties.

Finally, SLPs can serve a key role in supporting WM limitations in children. In addition to helping educators understand the relationship of WM difficulties to students' performance on language and academic tasks, SLPs can also help to identify and implement strategies and supports to reduce WM demands and improve the efficiency with which children use WM resources (both directly and indirectly). Minear and Shah (2006) suggested that given the contribution of WM resources to language and academic growth, even small improvements in the efficiency in WM may improve children's classroom performance. Thus, supporting WM limitations in children can be a valuable area of intervention for SLPs working with school-age children.

REFERENCES

Adams, A., Bourke, L., & Willis, C. (1999). Working memory and spoken language comprehension in young children. *International Journal of Psychology, 34,* 364–373.

Adams, A., & Gathercole, S. E. (1995). Phonological working memory and speech production in preschool children. *Journal of Speech, Language, and Hearing Research, 38,* 403–414.

Adams, A., & Willis, C. (2001). Language processing and working memory: A developmental perspective. In J. Andrade (Ed.), *Working memory in perspective* (pp. 79–100). New York, NY: Psychology Press.

Alloway, T. P. (2009). Working memory, but not IQ, predicts subsequent learning in children with learning difficulties. *European Journal of Psychological Assessment, 25,* 92–98.

Alloway, T. P., & Alloway, R. C. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology, 106,* 20–29.

Alloway, T. P., Gathercole, S. E., Adams, A. M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and other cognitive skills as predictors of progress toward early learning goals at school entry. *British Journal of Developmental Psychology, 23,* 417–426.

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The Working Memory Rating Scale: A classroom-based behavioral assessment of working memory. *Learning and Individual Differences, 19,* 242–245.

Archibald, L. M., & Gathercole, S. E. (2006). Short-term and working memory in specific language impairment. *International Journal of Language and Communication Disorders 41*(6), 675–693.

Archibald, L. M., & Joanisse, M. F. (2009). On the sensitivity and specificity of nonword repetition and sentence recall to language and memory impairments in children. *Journal of Speech, Language, and Hearing Research, 52,* 899–914.

Avons, S. E., Wragg, C. A., Cupples, L., & Lovegrove, W. J. (1998). Measures of phonological short-term memory and their relationship to vocabulary development. *Applied Psycholinguistics, 19,* 583–601.

Baddeley, A. D. (1990). The development of the concept of working memory: Implications and contributions of neuropsychology. In G. Vallar & T. Shallice (Eds.), *Neuropsychological impairments of short-term memory* (pp. 54–73). New York, NY: Cambridge University Press.

Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology, 49,* 5–28.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158–173.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York, NY: Academic Press.

Baddeley, A. D., & Hitch, G. J. (2000). Development of working memory: Should the Pascual-Leone and the Baddeley and Hitch models be merged? *Journal of Experimental Child Psychology, 77,* 128–137.

Berninger, V. W., Winn, W. D., Stock, P., Abbott, R. D., Eschen, K., Shi-Ju, L., Garcia, N., . . . Nagy, W. (2008). Tier 3 specialized writing instruction for students with dyslexia. *Reading and Writing, 21,* 95–129.

Bishop, D. V. M., North, T., & Donlan, C. (1995). Genetic basis of specific language impairment: Evidence from a twin study. *Developmental Medicine and Child Neurology, 37,* 56–71.

Bishop, D. V. M., North, T., & Donlan, C. (1996). Nonword repetition as a behavioral marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Psychiatry, 37,* 391–403.

Botting, N., & Conti-Ramsden, G. (2001). Nonword repetition and language development in children with specific language impairment. *International Journal of Communication Disorders, 36*(4), 421–432.

Boudreau, D. M. (2007). Narrative abilities in children with language impairment. In R. Paul (Ed.), *Language disorders from a developmental perspective* (pp. 331–356). Mahwah, NJ: Erlbaum.

Brocki, K. C., Randall, K. D., Bohlin, G., & Kerns, K. A. (2008). Working memory in school-aged children with attention-deficit/hyperactivity disorder combined type: Are deficits modality specific and are they independent of impaired inhibitory control? *Journal of Clinical and Experimental Neuropsychology, 30,* 749–759.

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology, 96,* 31–42.

Carretti, B., Borella, E., Cornoldi, C., & De Beni, R. (2009). Role of working memory in explaining performance of individual with specific reading comprehension deficits: A meta-analysis. *Learning and Individual Differences, 19,* 246–251.

Cicerone, K. D. (2002). Remediation of "working attention" in mild traumatic brain injury. *Brain Injury, 16,* 185–195.

Conti-Ramsden, G., & Durkin, K. (2007). Phonological short-term memory, language, and literacy: Developmental relationships in early adolescence in young people with SLI. *Journal of Child Psychology and Psychiatry, 48,* 147–156.

Cowan, N. (1998). Short-term memory, working memory, and their importance in language processing. *Topics in Language Disorders, 17,* 1–18.

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450–466.

De Jong, P. F. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology, 70,* 75–96.

Dollaghan, C., & Campbell, T. F. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research, 41,* 1136–1146.

Dollaghan, C., Campbell, T., Needleman, H., & Janosky, G. (1997). Reducing bias in language assessment: A processing-dependent measure. *Journal of Speech, Language, and Hearing Research, 40,* 519–525.

Duff, S. C., & Logie, R. H. (2001). Processing and storage in working memory span. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 54A,* 31–48.

Edwards, J., Beckman, M., & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in novel word repetition. *Journal of Speech, Language, and Hearing Research, 47,* 421–436.

Ellis Weismer, S., & Edwards, J. (2006). The role of phonological storage deficits in specific language impairment: A reconsideration. *Applied Psycholinguistics, 27,* 556–562.

Ellis Weismer, S., & Evans, J. (2002). The role of processing limitations in early identification of specific language impairment. *Topics in Language Disorders, 22,* 15–29.

Ellis Weismer, S., Evans, J., & Hesketh, L. J. (1999). An examination of verbal working memory capacity in children with specific language impairment. *Journal of Speech and Hearing Research, 42,* 1249–1260.

Ellis Weismer, S., & Hesketh, L. J. (1996). Lexical learning by children with specific language impairment: Effects of linguistic input presented at varying speaking rates. *Journal of Speech and Hearing Research, 39,* 177–190.

Ellis Weismer, S., Plante, E., Jones, M., & Tomblin, J. B. (2005). A functional magnetic resonance imaging investigation of verbal working memory in adolescents with specific language impairment. *Journal of Speech, Language, and Hearing Research, 48,* 405–425.

Ellis Weismer, S., Tomblin, J. B., Zhang, X., Buckwalter, P., Chynoweth, J. G., & Jones, M. (2000). Nonword repetition performance in school-age children with and without language impairment. *Journal of Speech, Language, and Hearing Research, 43,* 865–868.

Engel, P. M. J., Santos, F. H., & Gathercole, S. E. (2008). Are working memory measures free of socioeconomic influence? *Journal of Speech, Language, and Hearing Research, 51,* 1580–1587.

Engle, R. W. (2001). What is working memory capacity? In H. L. Roediger, J. S. Nairne, I. Neath, & A. M. Suprenant (Eds.), *The nature of remembering: Essays in honor of Robert G. Crowder,* (pp. 297–314). Washington, DC: American Psychological Association.

Fazio, B. B. (1996). Serial memory in children with specific language impairment: Examining specific content areas for assessment and intervention. *Topics in Language Disorders, 17*(1), 58–71.

Gale, R. (2003). *Stanford-Binet Intelligence Scale* (5th ed.). Itasca, IL: Riverside.

Gathercole, S. E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition, 23,* 83–94.

Gathercole, S. E. (2008). Working memory in the classroom. *The Psychologist, 21*(5), 382–385.

Gathercole, S. E., & Alloway, T. P. (2008). Working memory and classroom learning. In S. K. Thurman & C. A. Fiorello (Eds.), *Applied cognitive research in K–3 classrooms* (pp. 17–40). New York, NY: Routledge/Taylor & Francis Group.

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93,* 265–281.

Gathercole, S. E., & Baddeley, A. D. (1990a). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29,* 336–360.

Gathercole, S. E., & Baddeley, A. D. (1990b). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology, 81,* 439–454.

Gathercole, S. E., & Baddeley, A. D. (1993a). Phonological working memory: A critical building block for reading development and vocabulary acquisition. *European Journal of Psychology of Education, 8,* 259–272.

Gathercole, S. E., & Baddeley, A. D. (1993b). *Working memory and language*. Hillsdale, NJ: Erlbaum.

Gathercole, S. E., & Baddeley, A. D. (1996). *The Children's Test of Nonword Repetition*. London, England: The Psychological Corporation.

Gathercole, S. E., Brown, L., & Pickering, S. J. (2003). Working memory assessments at school entry as longitudinal predictors of national curriculum attainment levels. *Educational and Child Psychology, 20,* 109–122.

Gathercole, S. E., Lamont, E., & Alloway, T. P. (2004). Working memory in the classroom. In S. J. Pickering & G. D. Phye (Eds.), *Working memory and education* (pp. 219–240). Hillsdale, NJ: Erlbaum.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at seven years of age. *British Journal of Educational Psychology, 70,* 177–194.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18,* 1–16.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28,* 887–898.

Gaulin, C. A., & Campbell, T. F. (1994). Procedure for assessing verbal working memory in normal school-aged children: Some preliminary data. *Perceptual and Motor Skills, 79,* 55–64.

Georgiou, G. K., Parrila, R., & Papadopoulos, T. C. (2008). Predictors of word decoding and reading fluency across languages varying in orthographic consistency. *Journal of Educational Psychology, 100,* 566–580.

Gill, C. B., Klecan-Aker, J., Roberts, T., & Fredenburg, K. A. (2003). Following directions: Rehearsal and visualization strategies for children with specific language impairment. *Child Language Teaching and Therapy, 19,* 85–104.

Gillam, R. B. (1997). Putting memory to work in language intervention: Implications for practitioners. *Topics in Language Disorders, 18,* 72–79.

Gillam, R. B., Hoffman, L. M., Marler, J. A., & Wynn-Dancy, M. L. (2002). Sensitivity to increased task demands: Contributions from data-driven and conceptually driven information processing deficits. *Topics in Language Disorders, 22,* 30–48.

Gillam, R. B., & van Kleek, A. (1996). Phonological awareness training and short-term working memory: Clinical implications. *Topics in Language Disorders, 17,* 72–81.

Gilliver, M. L., & Byrne, B. (2009). What's in a name? Preschoolers' noun learning performance in relation to their risk for reading disability. *Reading and Writing, 22,* 637–659.

Glenberg, A. M., Brown, M., & Levin, J. R. (2007). Enhancing comprehension in small reading groups using a manipulation strategy. *Contemporary Educational Psychology, 32,* 389–399.

Glenberg, A. M., Jaworski, B., & Rischal, M. (2005). *Improving reading improves math*. Unpublished manuscript, University of Wisconsin, Madison.

Gupta, P., & Tisdale, J. (2009). Does phonological short-term memory causally determine vocabulary learning? Toward a computational resolution of the debate. *Journal of Memory and Language, 61,* 481–502.

Hitch, G. J., Towse, J. N., & Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology, 130*(2), 194–198.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12,* 9–15.

Hood, J., & Rankin, P. M. (2005). How do specific memory disorders present in the school classroom? *Pediatric Rehabilitation, 8,* 272–282.

Horohov, J. E., & Oetting, J. B. (2004). Effects of input manipulations on the word learning abilities of children with and without specific language impairment. *Applied Psycholinguistics 25,* 43–65.

Hutchinson, J., & Marquardt, T. P. (1997). Functional treatment approaches to memory impairment following brain injury. *Topics in Language Disorders, 18,* 45–57.

Imbo, I., & Vandierendonck, A. (2007). The development of strategy use in elementary school children: Working memory and individual differences. *Journal of Experimental Child Psychology, 96,* 284–309.

Isaki, E., Spaulding, T. J., & Plante, E. (2008). Contributions of language and memory demands to verbal memory performance in language-learning disabilities. *Journal of Communication Disorders, 41,* 512–530.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Science in the United States of America, 105,* 6829–6833.

Jarrold, C. (2001). Applying the working memory model to the study of atypical development. In J. Andrade (Ed.), *Working memory in perspective* (pp. 126–150). Philadelphia, PA: Psychology Press.

Jones, G., Gobet, F., & Pine, J. M. (2007). Linking working memory and long-term memory: A computational model of the learning of new words. *Developmental Science, 10,* 853–873.

Just, M., & Carpenter, P. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99,* 122–149.

Kail, R. (1990). *The development of memory in children* (3rd ed.). New York, NY: W. H. Freeman/Times Books.

Klingberg, T., Fernell, W., Oelson, P., Johnson, M., Gustafsson, P., Dahltrom, K., . . . Westerberg, H. (2001). *Cognitive memory training program*. Upper Saddle River, NJ: Pearson Education.

Klingberg, T., Fernell, W., Oelson, P., Johnson, M., Gustafsson, P., Dahltrom, K., . . . Westerberg, H. (2005). Computerized

training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44,* 177–186.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24,* 781–791.

Klingner, J. K., Vaughn, S., & Boardman, A. (2007). *Teaching reading comprehension to students with learning difficulties*. New York, NY: Guilford Press.

Lahey, M., & Bloom, L. (1994). Variability and language learning disabilities. In G. P. Wallach & K. G. Butler (Eds.), *Language learning disabilities in school-age children and adolescents* (pp. 354–372). New York, NY: MacMillan.

Leonard, L. B., Ellis Weismer, S., Miller, C. A., Francis, D. J., Tomblin, B., & Kail, R. V. (2007). Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research, 50,* 408–428.

Lindblom, B. (1989). Some remarking on the origin of the phonetic code. In A. von Euler, I. Lundberg, & G. Lennerstrand (Eds.), *Brain and reading,* (pp. 27–44). Cambridge, MA: MIT Press.

Maridaki-Kassotaki, K. (2002). The relation between phonological memory skills and reading ability in Greek-speaking children: Can training of phonological memory contribute to reading development? *European Journal of Psychology of Education 17,* 63–73.

Marton, K. (2008). Visuo-spatial processing and executive functions in children with specific language impairment. *International Journal of Language & Communication, 43,* 181–200.

Marton, K., Kelmenson, L., & Pinkhasova, M. (2007). Inhibition control and working memory capacity in children with SLI. *Psychologia, 50,* 110–121.

McCabe, A., & Bliss, L. S. (2003). *Patterns of narrative discourse*. New York, NY: Allyn & Bacon.

Minear, M., & Shah, P. (2006). Sources of working memory deficits in children and possibilities for remediation. In S. E. Pickering & G. D. Phye (Eds.), *Working memory and education* (pp. 273–297). Mahwah, NJ: Erlbaum.

Montgomery, J. W. (1995). Sentence comprehension in children with specific language impairment: The role of phonological working memory. *Journal of Speech and Hearing Research, 38,* 187–199.

Montgomery, J. W. (2000a). Relation of working memory to offline and real-time sentence processing in children with specific language impairment. *Applied Psycholinguistics, 21,* 117–148.

Montgomery, J. W. (2000b). Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 43,* 293–308.

Montgomery, J. W. (2002). Understanding the language difficulties of children with specific language impairments: Does verbal working memory matter? *American Journal of Speech-Language Pathology, 11,* 77–91.

Montgomery, J. W., & Evans, J. L. (2009). Complex sentence comprehension and working memory in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 52,* 269–288.

Montgomery, J. W., Magimairaj, B. M., & Finney, M. C. (2010). Working memory and specific language impairment: An update on the relation and perspectives on assessment and treatment. *American Journal of Speech-Language Pathology, 19,* 78–94.

Montgomery, J., Magimairaj, B., & O'Malley, M. (2008). The role of working memory in typically developing children's complex sentence comprehension. *Journal of Psycholinguistic Research, 37,* 331–354.

Montgomery, J. W., Polunenko, A., & Marinellie, S. A. (2009). Role of working memory in children's understanding of spoken narrative: A preliminary investigation. *Applied Psycholinguistics, 30,* 485–509.

Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology, 73,* 139–158.

Oetting, J. B., & Cleveland, L. H. (2006). The clinical utility of nonword repetition for children living in the rural south of the US. *Clinical Linguistics & Phonetics, 20,* 553–561.

Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience, 7,* 75–79.

O'Shaughnessy, T. E., & Swanson, H. L. (1998). Do immediate memory deficits in students with learning disabilities in reading reflect a developmental lag or deficit?: A selective meta-analysis of the literature. *Learning Disability Quarterly, 21,* 123–148.

O'Shaughnessy, T. E., & Swanson, H. L. (2000). A comparison of two reading interventions for children with reading disabilities. *Journal of Learning Disabilities, 33,* 257–277.

Parente, R., Kolakowsky-Hayner, S., Krug, K., & Wilk, C. (1999). Retraining working memory after traumatic brain injury. *NeuroRehabilitation, 13,* 157–163.

Passolunghi, M. C., & Siegel, L. S. (2004). Working memory and access to numerical information in children with disability in mathematics. *Journal of Experimental Child Psychology 88,* 348–367.

Pickering, S. J., & Gathercole, S. (2001). *Working Memory Test Battery for Children*. Minneapolis, MN: PsychCorp/Pearson.

Quail, M., Williams, C., & Leitao, S. (2009). Verbal working memory in specific language impairment: The effect of providing visual support. *International Journal of Speech-Language Pathology, 11,* 220–233.

Rankin, P. M., & Hood, J. (2005). Designing clinical interventions for children with specific memory disorders. *Pediatric Rehabilitation, 8,* 283–297.

Riccio, C. A., Cash, D. L., & Cohen, M. J. (2007). Learning and memory performance of children with specific language impairment (SLI). *Applied Neuropsychology, 14,* 255–261.

Ricks, T. R., & Wiley, J. (2009). The influence of domain knowledge on the functional capacity of working memory. *Journal of Memory and Language, 61,* 519–537.

Rodekohr, R. K., & Haynes, W. O. (2001). Differentiating dialect from disorder—A comparison of two processing tasks and a standardized language test. *Journal of Communication Disorders, 34,* 255–272.

Salthouse, R., Mitchell, D., Skovronek, E., & Babcock, R. (1989). Effects of adult age and working memory on reasoning, and spatial abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 507–516.

Seigneuric, A., & Ehrlich, J. (2005). Contributions of working memory capacity to children's reading comprehension: A longitudinal investigation. *Reading and Writing, 18,* 617–656.

Seigneuric, A., Ehrlich, J., Oakhill, J. V., & Yuill, N. M. (2000). Working memory resources and children's reading comprehension. *Reading and Writing: An Interdisciplinary Journal, 13,* 81–103.

Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical Evaluation of Language Fundamentals—Fourth Edition*. San Antonio, TX: The Psychological Corporation.

Snyder, L. E., Dabasinskas, C., & O'Connor, O. (2002). An information processing perspective on language impairment in children: Looking at both sides of the coin. *Topics in Language Disorders, 22*(3), 1–14.

Sohlberg, M. M., Mateer, C. A., & Struss, D. T. (1993). Contemporary approaches to the management of executive control dysfunction. *Journal of Head Trauma Rehabilitation, 81,* 45–58.

St. Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology, 30,* 203–219.

Swanson, H. L., & Berninger, V. (1995). The role of working memory in skilled and less skilled readers' comprehension. *Intelligence, 21,* 83–108.

Swanson, H. L., Cochran, K. F., & Ewers, C. A. (1989). Working memory in skilled and less skilled readers. *Journal of Abnormal Child Psychology, 17,* 145–156.

Swanson, H. L., & Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology, 96,* 249–283.

Swanson, H. L., Kehler, P., & Jerman, O. (2010). Working memory, strategy knowledge, and strategy instruction in children with reading disabilities. *Journal of Learning Disabilities, 43*(1), 24–47.

Swanson, H. L., & Sachse-Lee, C. (2001). Mathematical problem solving and working memory in children with learning disabilities: Both executive and phonological processes are important. *Journal of Educational Psychology, 96,* 471–491.

Thordardottir, E. (2008). Language-specific effects of task demands on the manifestation of specific language impairment: A comparison of English and Icelandic. *Journal of Speech, Language, and Hearing Research, 51,* 922–937.

Thorell, L. B., Lindqvist, S., Nutley, S. B., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12,* 106–113.

Tompkins, C. A. (1995). *Right hemisphere communication disorders: Theory and management*. San Diego, CA: Singular.

Torppa, M., Poikkeus, A., Laakso, M., Eklund, K., & Lyytinen, H. (2006). Predicting delayed letter knowledge development and its relation to Grade 1 reading achievement among children with and without familial risk for dyslexia. *Developmental Psychology, 42,* 1128–1142.

Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language, 49,* 446–468.

Vallat, C., Azouvi, P., Hardisson, H., Meffert, R., Tessier, C., & Pradat-Diehl, P. (2005). Rehabilitation of working memory after left hemisphere stroke. *Brain Injury, 19,* 1157–1164.

Vanderberg, R., & Swanson, H. L. (2007). Which components of working memory are important in the writing process? *Reading and Writing, 20,* 721–752.

van Kleek, A., Gillam, R. B., & McFadden, T. U. (1998). A study of classroom-based phonological awareness training for preschoolers with speech and/or language disorders. *American Journal of Speech-Language Pathology, 7,* 65–76.

Vukovic, R. K., & Siegel, L. S. (2010). Academic and cognitive characteristics of persistent mathematics difficulty from first through fourth grade. *Learning Disabilities Research & Practice, 25,* 25–38.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *Comprehensive Test of Phonological Processing*. Austin, TX: Pro-Ed.

Wechsler, D., Kaplan, E., Fein, D., & Kramer, R. (2004). *Wechsler Intelligence Scale for Children—IV.* San Antonio, TX: Harcourt Assessment.

Wexler, B. E., Anderson, M., Fulbright, R. K., & Gore, J. C. (2000). Preliminary evidence of improved verbal working memory performance and normalization of task-related frontal lobe activation in schizophrenia following cognitive exercises. *American Journal of Psychiatry, 157,* 1694–1696.

Wynn Dancy, M. L., & Gillam, R. B. (1997). Accessing long-term memory: Metacognitive strategies and strategic action in adolescents. *Topics in Language Disorders, 18,* 32–44.

Yuill, N., Oakhill, J., & Parkin, A. (1989). Working memory, comprehension ability, and the resolution of text anomaly. *British Journal of Psychology, 80,* 351–361.